NEW ELECTRICAL CONTROL METHODS TO PREVENT POWER PLANT FOULING

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Abstract

One new non-chemical method for removal of biofouling utilizes pulsed acoustic waves above the cavitation threshold to remove accumulated scale and/or biofouling from the inside walls of piping and other enclosed structures. The pulsed acoustic wave successively removes accumulated deposits as the arc-discharge source is moved down the tube by an operator. We describe a program developing a compact, portable tube-cleaning system for use in utility and U.S. Navy scheduled plant maintenance. Results from a laboratory demonstration with typical heat-exchanger tubing taken from a Tennessee Valley Authority power plant are presented. In addition results from a field experiment conducted at the U.S. Navy Marine Corrosion Test Facility, Ft. Lauderdale, Florida, are presented that demonstrated significant (order of magnitude) reduction in biofouling associated with pulsed acoustic shock wave treatment at intensities below the cavitation threshold.

I. Introduction

Heat exchangers and other power plant related equipment represent critical operational and maintenance concerns. Scale formation and biofouling in power plant steam condenser tubes, in service water piping, and in process-liquid piping (manufacturing) are wide spread phenomena.[1] Biofouling and the resultant corrosion can be major factors in reducing the operating capacity of these systems. Since overrating these systems to account for the degradation in performance can be self-defeating, especially with heat exchangers,[2] there is a need for improved prevention technology. The choice of prevention technology is determined not only by economic factors such as maintenance costs and fuel efficiency, but also by environmental concerns related to the methods used to remediate the fouling. Chemical treatment, either for removal by acid treatment or for prevention by water chemistry control, is a typical remedy. Research into non-chemical methods for prevention of biofouling is justified by the costs associated with current methods and policies. As a result, a recent Tennessee Valley Authority (TVA) sponsored workshop[3] noted several emerging electrical technologies as candidates for the control of biofouling, including the zebra mussel, in both electric utility and ship board systems. These technologies can be separated into remediation methods (i.e., removal of existing fouling) and prevention methods.

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14. ABSTRACT
One new non-chemical method for removal of biofouling utilizes pulsed acoustic waves above the cavitation threshold to remove accumulated scale and/or biofouling from the inside walls of piping and other enclosed structures. The pulsed acoustic wave successively removes accumulated deposits as the arc-discharge source is moved down the tube by an operator. We describe a program developing a compact, portable tube-cleaning system for use in utility and U.S. Navy scheduled plant maintenance. Results from a laboratory demonstration with typical heat-exchanger tubing taken from a Tennessee Valley Authority power plant are presented. In addition results from a field experiment conducted at the U.S. Navy Marine Corrosion Test Facility, Ft. Lauderdale, Florida, are presented that demonstrated significant (order of magnitude) reduction in biofouling associated with pulsed acoustic shock wave treatment at intensities below the cavitation threshold.

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One new remediation method utilizes pulsed acoustic waves at intensities above the cavitation threshold to remove accumulated scale and/or biofouling from the inside walls of piping and other enclosed structures. For example, we have demonstrated the removal of biofouling and scale from the inside of water-filled tubes by repetitively striking an arc at the end of a coaxial cable.[4] The pulsed acoustic wave successively removes accumulated deposits as the arc-discharge source is moved down the tube by an operator. This technique has the advantages of chemical removal, namely no physical contact with the tube walls, and the advantages of mechanical removal via scrapers, namely no chemical waste stream. Remediation of zebra mussel fouling with acoustic shock waves has been studied,[5] and while the method may be effective, questions of collateral damage to concrete structures from the scouring and disruptive effect of cavitation was a concern voiced by the power-plant operational community.[3]

An alternative we are studying is to use *low-energy* acoustic shock waves to prevent biofouling. We have completed a preliminary experiment at the Marine Corrosion Test Facility in Ft. Lauderdale, Florida in which acoustic shock waves were shown to reduce the growth rate of micro- and macrofouling in a sea water test loop. The prevention effect was observed upstream as well as downstream at ranges that excluded effects from cavitation and ultra-violet (UV) illumination. Since the test loop was made of clear plastic pipe and suffered no observable degradation due to exposure to the low-energy pulsed acoustic waves, we are optimistic that a prevention system prototype can be developed that avoids the concerns over collateral damage while producing a valuable prevention effect. As will be described below, the effect is based on physical mechanisms as opposed to chemical, and thus should have minimal environmental impact. However, a study extending this result to freshwater biofouling, and especially the zebra mussel problem, is still required.

II. Remediation with Pulsed Acoustic Waves

The pulsed acoustic (hydraulic shock wave) can be used to successively remove accumulated mineral deposits (scale) within interior piping (especially with bends, elbows, and valves), heat exchanger tubes, and steam condenser tubes. The shock wave is generated by an arc-discharge source which is moved down the tube by an operator.

A power modulator has been constructed which is basically a spark-gap switched capacitive discharge circuit with appropriate safety features such as a fast ground-fault-interrupt circuit, an operator remote control, and safety interlocks. The capacitor is charged by a Maxwell CCDS constant-current power supply. The capacitor, typically charged to 50 J at 10 kV, is discharged through a Phenix Technologies spark-gap switch operated in self-breakdown to the center conductor of a 30-m length of RG-8 coaxial cable. The high-voltage pulse is conducted to an "applicator" tip which is submerged in the water-filled tube or pipe to be cleaned. The resulting underwater electrical arc conducts an electrical current of about 1 kA with a risetime of about 1 μs. This has already been shown to produce at least a 10 MPa shock wave with a risetime of about 0.5 μs.[4] The pulse is repeated at a pulse repetition frequency (PRF) of a few tens of Hertz or less.

Eight 2.54 cm (1 in.) diameter tubes were delivered to the Mississippi State University High Voltage Laboratory by TVA. Each tube is approximately 3 m long. The tubes were removed from a heat exchanger and sawed into the eight pieces. All eight tubes were observed on arrival at MSU to be coated on the inside surfaces with a brown dirt-like film (scale). In all the tubes the film had completely dried before testing could begin. Nevertheless, the majority of the film remained adhered to the inside surfaces of the tubes along their entire length. The power modulator was set for 9.5 kV (45 J) and a repetition rate of either 11 Hz or 22 Hz. Thus the average output power was either 500 W or 1000 W (note that the acoustic power generated by the electrical discharges contain only a small fraction of this power).

Of the six tubes used during the "cleaning" experiment, two were cleaned only with flowing water to act as controls. The other four were cleaned with a combination of flowing water and acoustic pulses

generated at the applicator tip which was methodically moved down the length of the pipe by an operator. The flow rate of the water was kept constant at 14 l/min.

The primary result of cleaning only with water was the flushing of the loose dirt dislodged during shipping. A visual inspection from either end of both tubes revealed large flakes of dirt continuing to adhere to the inside of the tubes. In a power plant environment, it is expected that water flowing at the relatively low rate of 14 l/min. will have little cleaning effect.

In contrast, the four tubes treated with acoustic pulses appeared to have been cleaned down to the bare metal. The tubes were subjected to different exposure times ranging from 30 to 120 s and the two different PRFs. The result was the same for all four permutations: apparently complete removal of dirt adhering to the tube walls as determined by visual inspection at either end of the tubes.

The technical feasibility of cleaning tubes and pipes with acoustic pulses (shock waves) has been demonstrated. However, the suitability of using acoustic pulses generated by a properly designed system for tube cleaning is essentially an economic question. A challenging economic competitor are mechanical bushes which are blown through tubes with compressed air at relatively low economic and environmental cost. However, there are other more suitable applications for the acoustic technique. For example, the reported cost of cleaning the Public Service of Indiana's Wabash River Unit Six steam condenser (~9,000 32-ft. tubes) with formic acid is approximately $56,000, or 19.4¢/ft. Mechanical cleaning was not considered for this unit because the age of the condenser is such that unacceptable damage may be incurred in the tubes. In contrast, these tubes could be cleaned by acoustic pulses without generating hazardous waste at a cost comparable to brush cleaning.

The payoff for nuclear plants may be even greater. For example, it cost approximately 35¢/ft.[6] to remove approximately 75% of the scale build-up in a Westinghouse CPS steam condenser at a large nuclear power plant.[7] In this particular plant, 80 tons of calcium carbonate scale was removed by mechanical means (multiple passes with air-driven scale cutters and scrapers) in six weeks during a 1992 scheduled outage for refueling.

In addition, it is clear the the brush method is fundamentally unsuitable for cleaning pipes with elbows and joints, such as in the extensive "service water" piping found in power plants, but that the flexible coaxial cable used to electrically connect and to advance the applicator tip can be used in at least some of these applications. Further field testing at a TVA power plant is planned to demonstrate this capability.

III. Prevention with Pulsed Acoustic Waves

Sonics for biofouling control has been studied for many years.[8] Recently, conventional ultrasonic sources have been field tested for possible prevention of the freshwater zebra mussel (*Dreissena polymorpha*).[3] While these techniques are viewed by at least one major customer, the electric utilities, as still too experimental,[9] further research seems justified.[3]

Pulsed acoustic shock wave technology differs from conventional sonic/ultrasonic technologies in several important respects. First, the cavitation threshold is much higher for short-pulse, high-frequency (<1-μs duration, >1-MHz carrier) acoustic waves than for low-frequency (~10 kHz), continuous-wave (CW) ultrasonics: 10 MPa and 0.1 MPa respectively.[10] Second, the equipment used to produce an underwater pulsed shock wave is fundamentally different.

The pulsed acoustic technique applied to biofouling control accrues two advantages from the higher cavitation threshold. First, more acoustic power can be delivered to the water at higher efficiency, thus

allowing larger areas to be treated at greater range. Second, in the case of conventional ultrasonics, the biofouling control mechanism has been correlated to cavitation,[3,11] which places the equipment and ancillary protective coatings at risk of short and long term damage due to the corrosive effect of cavitation. Based on data with pulsed acoustic waves to be described next, biofouling control from shock-wave treatment does not appear to be related to cavitation. Thus, a higher cavitation threshold allows a larger area to be treated at greater range while also reducing collateral damage.

In the area of equipment, high-power (tens of kilowatts) CW ultrasonic equipment tends to be sophisticated, particularly if swept frequency signals are required as suggested by some reports.[12] In contrast, the equipment required to produce pulsed acoustic shock waves uses underwater electrical-discharges formed by simple, relatively inexpensive arc-discharge equipment.

However, pulsed acoustics have received comparatively little study. One study, originally designed to demonstrate zebra mussel control, reported effective prevention of algae buildup in freshwater piping over a range exceeding 15 m.[13] This range apparently eliminates a cavitation-related effect. Unfortunately, the lack of adequate control for this study and the poor statistical design made the interpretation of the results difficult. The zebra mussel data were inconclusive.

We have recently completed an independent study of biofouling control with pulsed acoustic waves in sea water. The acoustic pulse source consisted of a high-voltage power supply that produced an underwater electrical arc discharge. The repetition rate of the acoustic pulse was 0.5 Hz (once every two seconds). The experiment was conducted for the Naval Surface Warfare Center, Dahlgren Division at the Marine Corrosion Test Facility in Ft. Lauderdale, Florida (15 Feb.-27 Feb. 1994). The experiment demonstrated effective non-chemical biofouling prevention both upstream and downstream of the acoustic source. Specifically, this experiment demonstrated a significant reduction in the rate of micro and macro biofouling, with respect to an untreated control, in a sea water test loop treated with pulsed acoustic waves. Based on counts of plated cultures, at least an order-of-magnitude reduction in bacteria settling was observed at ranges of at least 10 feet for acoustic pulse treatments of less than 25 W average power (4 W/sq. ft. treated) for 10 hours each day. Direct observation of treated and untreated surfaces with an environmental scanning electron microscope (ESEM) revealed nearly complete prevention of bacterial and algae settling against significant fouling of the control. No degradation to the 2-inch-diameter, schedule-40 clear PVC plastic pipe was observed.

These effects occurred at ranges that exclude the influence of cavitation and ultraviolet illumination. The mechanism involves the interaction of the acoustic pulse with particles caught in boundary layers near the surface of all structures in contact with the flowing water column. This interaction reduces the effective "sticking coefficients" of the particles. The mechanism appears to be equally effective in preventing the accumulation of microscopic objects such as bacteria, algae, and larvae, as well as macroscopic objects such as sand. Since the effect is non-chemical, but confined to the range of the acoustic wave in the system being treated, it should be more environmentally compatible than competing chemical biocides and thermal treatments alone. Alternatively, experience with other techniques that influence boundary layer diffusion[14] makes it likely that biocides used in conjunction with pulsed acoustic treatment will be more effective, especially in low-flow stagnation regions. Since the focus is on prevention of settling at the microfouling level (including larvae-born invasions such as the zebra mussel) a collateral waste stream is all but avoided.

IV. Conclusions

While the tube cleaning experiment demonstrated that remediation of scale and biofouling with arc-generated shock waves is possible, the experiment also indicated that the effect is essentially local. The sea water biofouling prevention experiment demonstrated that pulsed acoustic waves can prevent biofouling over considerably greater ranges than they can remove biofouling (hundreds instead of tens of centimeters). This

is because biofouling prevention with pulsed acoustic waves appears to be possible at lower shock-wave intensities; specifically, at intensites below the cavitation threshold. Here high-voltage pulsed techniques may offer a significant advantage over conventional continuous-wave (CW) ultrasound because the higher cavitation threshold for short acoustic pulses allows higher peak intensities to be delivered to the water before encountering non-linear loss mechanisms which severely limit range. In addition, it is highly desirable to avoid long-term exposure of metal and concrete surfaces to intense cavitation because of the corrosion associated with cavitation. However, short-term exposure, such as during cleaning of mineral deposits from steam condenser tubes, probably poses little threat compared to the tube-wall damage caused by mechanical scraping or the tube-wall thinning caused by acid treatment. Further work will be required to verify this assumption. Additional follow-on work is required to quantify a freshwater biofouling prevention effect, especially on the zebra mussel. This can be accomplished by conducting a field experiment similar to that performed in sea water at the Marine Corrosion Test Facility.

Direct application of electric fields and currents for biofouling prevention is another possibility. Technology based on electrochemistry at surfaces is relatively advanced and has prior acceptance for corrosion control. However, cost and the potential for continuous release of heavy metals or other chemical toxins restrains this technology. The electric field "stun" or "kill" approaches have potential application in the long term, but the available evidence indicates a need for more study to establish reliable effects that can be developed for practical use.

References

1. Carl H. Fromm and Srinivas Budaraju, "Reducing equipment-cleaning wastes," *Chemical Engineering*, vol. 95, pp. 117-122, July 1988.

2. J. G. Knudsen, "Fouling of heat exchangers: Are we solving the problem?," *Chem. Eng. Prog.*, vol. 62(7), pp. 63-69, Feb. 1984.

3. Stephen Levy, "Final Report on Electrical Methods for the Control of Zebra Mussels," EPRI Power Electronics Applications Center, Knoxville, TN, May 1993.

4. M. G. Grothaus, M. S. Mazzola, M. Walch, and J. Jones-Meehan, "Pulsed power remediation and prevention of biofouling," Presented to 9th Inter. Pulsed Power Conf., Albuquerque, New Mexico, June 1993.

5. J. R. Duncan, M. Rader, S. Levy, I. Alexeff, J. A. Drake, J. Johnson, "The use of pulse power to control zebra mussels," Presented to 3rd Inter. Zebra Mussel Conf., Toronto, Ontario, Canada, Feb. 1993.

6. John L. Tsou, program manager for the Electric Power Research Institute's Plant Performance Program, private communication, May 1993.

7. R. David Thurston and Ronald L. Stiemsma, "Clinton Power Station Condenser Performance Evaluation and Improvement Program," Illinois Power Company Report.

8. J. M. Jones and B. Little, "USS PRINCETON (CG 59): Microbiologically influenced corrosion (MIC) and macrofouling status of sea water piping systems," Naval Surface Warfare Center Technical Report 90-176, June 1990.

9. T. J. Maiman, "Utility perspective," *Proc. Electric Utility Zebra Mussel Control Technology Conf.*, EPRI Technical Report 100434, pp. KA-19 to KA-20, 1992.

10. R. J. Urick, *Principles of Underwater Sound*, McGraw-Hill, New York, pp. 78-79, 1983.

11. Dennis T. Burton, Leonard B. Richardson, and Robert J. Taylor, "Control of Colonial Hydroid Macrofouling by Free-Field Ultrasonic Radiation," *Science*, vol. 223, pp. 1410-11, 1984.

12. E. C. Fischer and V. J. Castelli, "Technology for control of marine biofouling--a review," *Marine Biodeterioration: An Interdisciplinary Study*, Naval Institute Press, Annapolis, MD, p. 261, 1981.

13. A. Bryden, "New application of an acoustic device," Presented to 3rd Inter. Zebra Mussel Conf., Toronto, Ontario, Canada, Feb. 1993.

14. B. Costerton, "Control of Microbial Biofilm by Electrically Enhanced Biocide Treatment," *Proc. 12th Inter. Corrosion Congress*, vol. 5B, pp. 3803-06, 1993.